EVALUATION OF LO POWER LEVELING TECHNIQUES USED FOR REMOTE MIXING

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ABSTRACT

Operating microwave receivers with remote mixers in a system requires the LO power to be flat over broadband frequencies. In large systems, this is difficult to attain due to long RF cables. Most systems require significant engineering to ensure the LO power level to the mixer is adequate. To help understand the problem, commonly used techniques have been evaluated while recommending a particular approach.

Operating over a small fundamental frequency range with harmonic mixing has the advantage of lower RF cable insertion loss but results in high mixer conversion loss. Using negative slope equalizers and amplifiers, RF cable slope and attenuation can be sufficiently combated. However, this requires extensive system engineering and customization to match cable losses, thereby making it expensive. The approach is also designed to only work with a certain set of RF cables.

A more viable approach includes independently controlling the attenuators and amplifiers for the signal and reference channels which can be configured to provide optimal LO power to the respective mixer. A simple setup file configures components in each channel to adapt to any set of RF cables. Positive experimental results of implementing this technique in different configurations are presented.

Keywords: Accuracy, Design, Instrumentation, Measurement, Near-Field, Range, Advances in indoor and outdoor ranges

1. Introduction

Through interaction with engineers and technicians in many countries throughout the world, MI Technologies has had the opportunity to discuss and evaluate different techniques employed to drive LO power to remote mixers. This paper will identify, analyze and characterize these different techniques. In many large measurement ranges, the control equipment which includes the microwave receivers is usually placed in a rack in the control room. The remote mixers are mounted on positioners or situated at convenient locations in the range. Long RF cables are used to connect the control equipment to the mixers. It is always desirable to maintain a flat LO drive to the mixers across broadband frequencies. Driving the mixers with an optimal LO power also reduces the microwave receiver's sensitivity to change in temperature and variations due to time. Some of the main challenges that most system operators face are:

- In most systems, attenuators with fixed values are used in the LO path. Due to this, when cable lengths change or a cable is substituted for a different type, these attenuators have to be changed to adequately drive the remote mixer.
- If the LO power level is changed or components are swapped, extensive analysis and system engineering is needed to ensure that the remote mixers are driven with adequate LO signal.
- Broadband components are sold at premium prices. When the cost of engineering them into a design is added, it ends up being very expensive.
- Most range operators would like to independently control LO power levels going to the Signal remote mixer and Reference remote mixers which is currently unavailable.
- With current designs, it is cumbersome to adapt an existing system to meet new requirements without substantial re-engineering.

2. What is a Mixer?

Mixers are non-linear devices that multiply two input signals. Commonly used mixers are Schottky diodes which have fast switching speeds compared to other non-linear devices. Diodes are a square-law device [1], which means the function describing their non-linear behavior (current versus voltage) has a strong 2nd order component. This square law behavior is what generates the mixing product. The ideal mixer is shown in Figure 1. If the inputs are sinusoidal signals, the ideal mixer output is the sum and difference of the input frequencies, given by the equation below.

$$V_O = [A_1 \cos(\omega_1 t)][A_2 \cos(\omega_2 t)] =$$
$$\frac{A_1 A_2}{2}[\cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t]$$

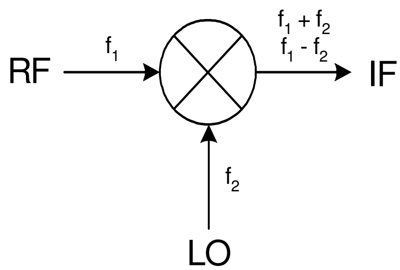

Figure 1 Ideal Mixer

In practice, the output spectrum includes several components:

The original inputs, the RF and LO signals, all higher order harmonics of RF and LO (m * RF and n * LO) where m and n are integer numbers, the two primary sidebands RF ± LO (m & n = 1), and the higher order products of (m * RF) ± (n * LO) [2].

The unwanted frequencies are typically removed with specific filters. The signal that is processed is the IF (intermediate frequency) which is usually lower than RF. It is easier and less expensive to implement better filters and low noise - high gain amplifiers at IF than at RF.

The mixing operation itself results in a loss of power. This is seen as the RF input signal is converted to the IF output. This loss is called the conversion loss. Variations in mixer design and LO power together impact the conversion loss. When the LO power is within an adequate range, typical mixer conversion loss numbers are between 5 to 10 dB.

Mixing techniques can be broken into two kinds: Fundamental mixing and Harmonic mixing [3].

When the fundamental LO frequency is directly used in the mixing operation, it is called fundamental mixing. The fundamental LO is mixed with the received RF signal to generate the sum or difference of the IF signal.

In harmonic mixing, the mixing LO signal is an integer multiple of the fundamental LO frequency which mixes with the received RF signal to generate the IF signal of interest. Using this approach, simpler and less expensive LO synthesizers are used as the frequency range of such devices do not have to be broadband. The trade off is that the conversion loss for such a process is much higher. This is because the power of the LO harmonics decreases rapidly with increasing harmonic number.

The main characteristic for driving Schottky diodes is referred to as the forward voltage. This is the voltage required to fully turn on the diode. The forward voltage typically varies from 0.2 V to 0.7 V. The LO input power to obtain the lowest conversion loss and best linearity should be enough to fully turn on the diode. For many commercially available mixers, an LO input power of +10dBm is considered adequate to fully turn on most mixer diodes [4].

When the LO input power level is reduced, such that the diode forward voltage is not overcome, the mixing operation loses efficiency and the result is an increase in conversion loss. This also leads to a decrease in the linear response of the mixer over the frequency range of the mixer as well as an increase in temperature sensitivity.

On the other hand, increasing the LO power to a level which is well above the optimum level required to fully turn on the diode might result in damage to the diode. For many commercially available mixers, an LO power level of +13dBm is considered to be the maximum operating LO drive level across a broadband range of frequencies.

3. Variation of power level and other parameters over frequency

One of the biggest challenges in antenna measurement systems is being able to consistently drive the remote mixers with adequate LO power over broadband frequencies.

Figure 2 shows a typical antenna measurement system. In far field systems, cable C2 can be quite long, typically ranging from 60ft to over 120ft. In such systems, maintaining a constant LO drive to the mixer is extremely difficult and an expensive process. Extensive system engineering is needed to achieve this. The control equipment is usually designed to meet LO drive requirements with RF components that are very expensive.

A crucial parameter which adds to the complexity of the design is the insertion loss slope exhibited by cables that work over broadband frequencies. **Figure 3** shows typical insertion loss values of commonly used RF cables over broadband frequencies. Some of the cables operate only up to 18GHz and some of them operate to 40GHz. The insertion loss exhibited by cables is calculated using the following equation:

*IL = K1 * sqrt(F) + K2 x F (dB/100 feet)*

Where,
IL is the insertion loss in dB,
K1 is the resistive loss constant
K2 is the dielectric loss constant
F frequency in MHz

If the cable type is known and the insertion loss in dB/ft is known for that cable, then a more practical equation to quickly calculate the insertion loss is:

*IL = loss in db/ft for cable * cable length in feet + 2*C*sqrt(f)*

Where,
IL is the insertion loss in dB,
f is frequency in GHz
C is a constant which varies according to connector type. Commonly used values for 'C' are:

Connector type	Value of 'C'
SMA	0.03
N	0.045
K	0.06

4. Techniques used for driving remote mixers

This section evaluates different techniques used to drive remote mixers in large systems and identifies the pros and cons of each.

A common technique used to drive LO power to the remote mixer includes the use of an LO repeater or extender unit. These units are usually placed in the middle of the range so that the LO signal can be amplified to adequate levels. LO extender designs usually vary from simple ones to extremely complex designs based on the length of cable used, actual placement of the extender unit and frequency range of operation.

Simple designs usually include an RF low noise amplifier and an equalizer along with several other RF components that allow switching of signals. The RF LNA amplifies the LO signal to adequate levels. The equalizer provides negative slope equalization across the frequency band. This combined with the positive slope insertion loss profile of the RF cable flattens the overall LO signal response over frequency. Therefore the LO signal going into the remote mixer is relatively flat over a broadband frequency range.

In more complex extender designs, linear RF amplifiers with higher output RF power are used. Amplifiers with solid gain flatness specifications are selected so that the gain will not vary too much over frequency. Equalizers are also used in this design, the difference being that these equalizers have a higher negative slope specification compared to the more basic extender design. With this approach, when cable types are changed in a range or increased in length, there is still enough negative slope available through the equalizer to account for the increased positive slope insertion loss of the longer cables.

Additional components which induce positive slope equalization are also added in case cable lengths end up being shorter than expected. **Figure 4** (below) shows a practical example of cable slope compensation. The positive slope of adding 1 and 2 RF cable coils have been compared to the negative slope of an equalizer. By adding the values on the Y axis, the overall insertion loss across the frequency band is higher, but the RF response over frequency ends up being more flat.

This approach has some disadvantages. Since every range is unique with cables of different lengths and different types, extensive system engineering is needed to ensure the component selection and design will meet system

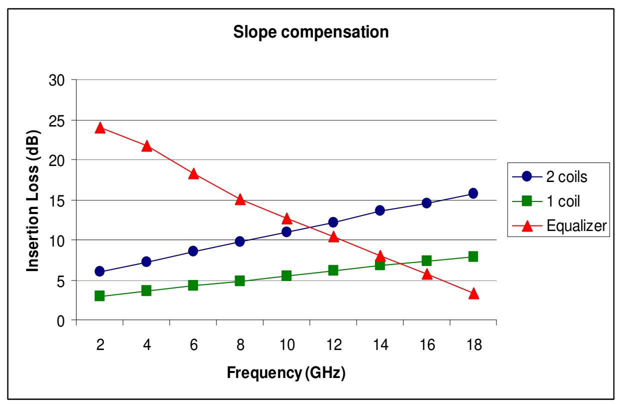

Figure 4 Slope compensation using positive slope equalization coils with a negative slope equalizer

requirements. Depending on the size of the range and types of cables used, expensive components are used to compensate for cable loss and insertion loss slope.

Additional components such as equalization coils, equalizers, attenuators, and other microwave components are usually needed to fine tune the design. Also the LO extenders are designed with components that will work with fixed known cable lengths and types. If the cable lengths change or the cable type changes, the design might no longer produce optimum results.

Due to this, cables can only be swapped out with other cables of the same type and length. If power levels are changed, the LO power will need to be measured and confirmed at different frequencies to make sure that the levels are not too high. While this approach works well for a fixed range configuration, it is not very flexible and relies heavily on re-engineering existing designs to make them work with different configurations. This proves to be a very difficult and expensive task to be performed every time components are swapped or changed.

Another approach is to use harmonic mixing. In harmonic mixing, higher multiples of the input LO is used to produce the mixing LO at the mixer. The advantage of this method is that the operational frequency range of the LO signal from the synthesizer can be more narrow, and less expensive RF cables can be used. Also, since the frequency range from the synthesizer is less broad, the RF signal variation is much flatter

The main disadvantage with harmonic mixing is the high conversion loss exhibited by mixers when they are driven by the higher order harmonics. In typical cases, observed conversion loss due to harmonic mixing is several orders of magnitude higher than the conversion loss at fundamental mixing. For example, the typical conversion loss at 18GHz for a mixer using fundamental mixing is 13dB. When the same mixer is operated using a 3rd order harmonic, viz. at 6GHz, the conversion loss varies from 26 – 32dB. In addition, higher the harmonic number, the greater the conversion loss.

The MI-750 Receiver implements a more dynamic approach that offers several advantages. It uses separate attenuators for the Signal and Reference channel mixers to automatically adjust and fine tune the LO power levels. The attenuator settings are adjusted to compensate for the cable length and frequency of operation, optimizing LO power at each mixer.

By using a configurable attenuator with fast switching speeds between different attenuation levels, any latency that is commonly associated between attenuation states is eliminated as long as this attenuator switches faster than the associated signal source. This attenuator provides several combinations of attenuation levels to adjust the LO levels going into the mixer. Initially, a list of attenuation values that is related to the frequency of operation and length of cable is created. The values are selected so that the overall response of LO power across frequency is flat. Due to latest advances in technology, GaN amplifiers are used in the design. They offer more power, work with higher voltages and operate well at hotter temperatures.

By paying close attention to design and packaging, many of the problems associated with traditional components are eliminated. Amplitude drift due to temperature is minimized by ensuring that air flow is constant over active components. **Figure 5** shows the fast switching between attenuation states. The attenuator is switched from the initial state to an attenuation of 0.5dB. In the figure, the switching time is faster than the sample rate of 4MSamples/sec used to collect the data. Thus the switching time is less than 250ns. The attenuator switching speed is expected to be much faster than any frequency switching speed likely to be encountered.

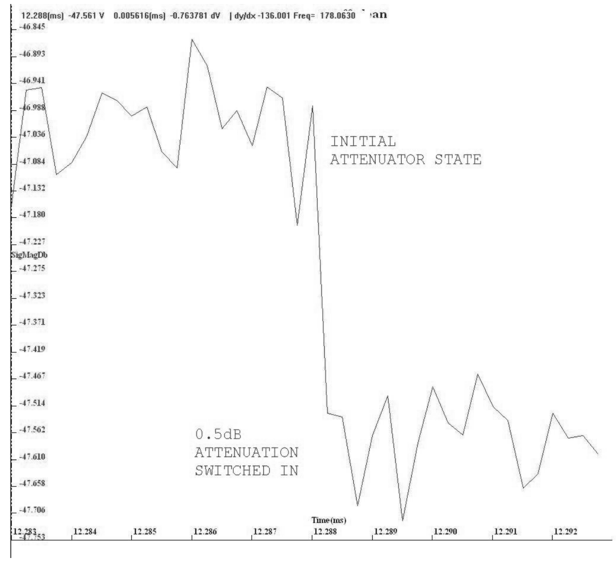

Figure 5: Attenuator switching speed

The MI-750 receiver has the capability to control the LO power on both the Signal and Reference channels independently. Due to this novel technique, there is no longer a requirement to exactly match cable lengths and cable types on the Signal and Reference channels. This feature will eliminate most of the system re-engineering that occurs when components in a range are changed and simplify range re-configuration. In this case, the range operator will only have to select the correct attenuation values and LO synthesizer power levels to drive the LO optimally to the mixers across different frequencies.

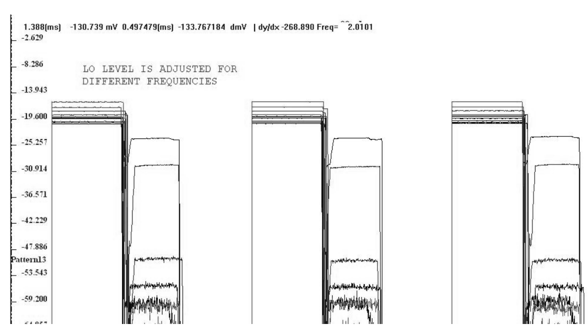

Figure 6: The software adjusts the attenuation values across different frequencies

Figure 6 shows that the LO drive to the mixer is adjusted automatically over different frequencies by adjusting the

LO power and attenuation values. The adjustment is very precise and across the entire frequency band, the variation is <1dB.

This aspect is very important for cable compensation. When cables are changed in a system, this approach compensates for change in cable loss by adjusting the attenuation level and the LO synthesizer power. A test set up used in the lab shows the actual attenuation values used in the Signal and Reference channels to reach the optimum LO level to the mixers.

Figure 7 is a graph of the output 'attenuation value' file from the receiver that shows how the attenuation values change across frequencies when cables are swapped. For this test, a short cable 18" long and a long lossy cable 75" long were used. The receiver maintains a file with the attenuation values and the LO power level versus frequency. These values have been plotted in a graph with the X axis being the frequency and the Y axis being the attenuation values. The user can change the file values as necessary via a built-in Web page interface.

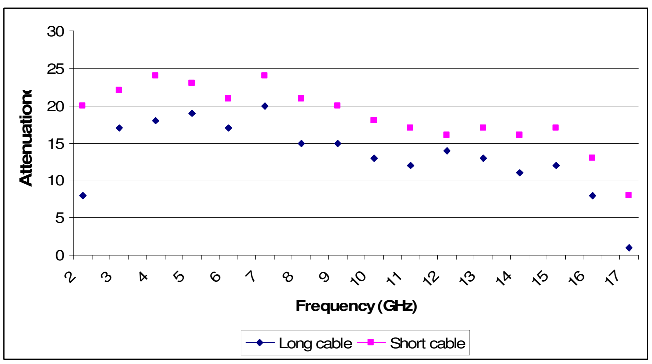

Figure 7: Plot of output attenuation values across different frequencies

5. Summary

The main goal of this paper was to analyze and discuss different techniques used for LO power leveling in remote mixers. The pros and cons of different techniques have been discussed at length and reviewed. With advances in technology and RF component design, several smart functions can now be performed by receivers used in antenna measurement ranges. Empirical data and measurements are shown in this paper which elaborates on some of the techniques commonly employed in test ranges today. The new dynamic approach and methodology discussed in the final sections of the paper has been implemented in the MI-750 receiver that adapts to range conditions.

6. References

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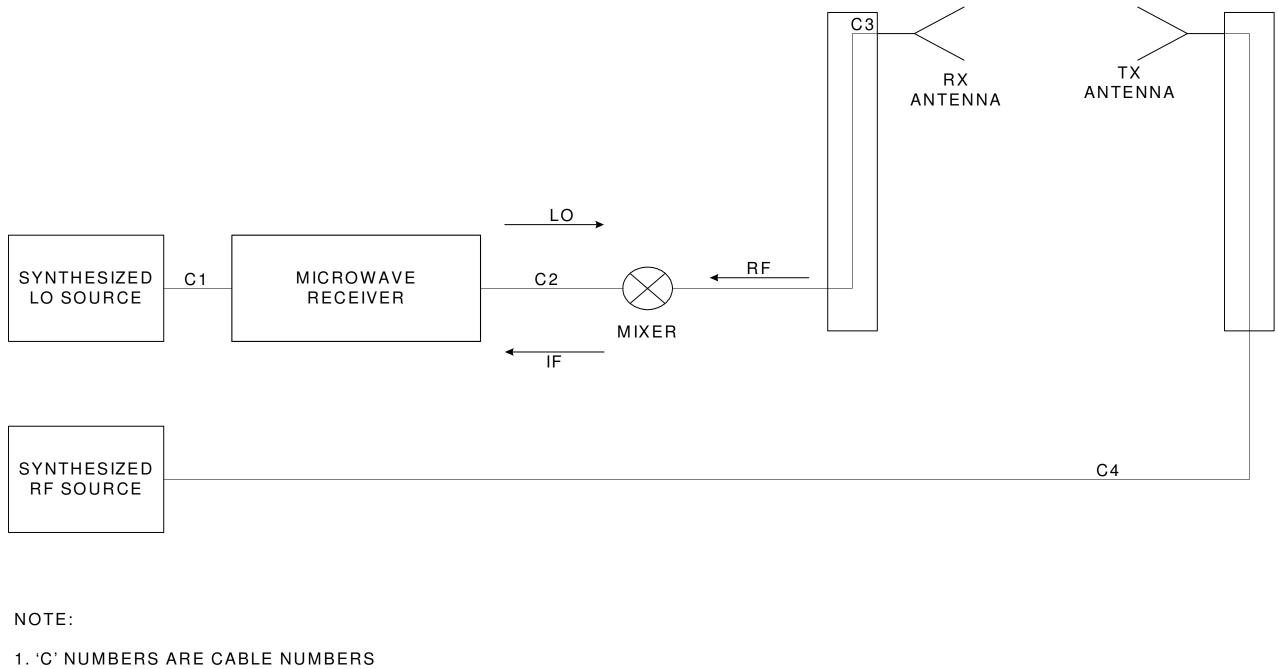

Figure 2 – Typical antenna measurement system

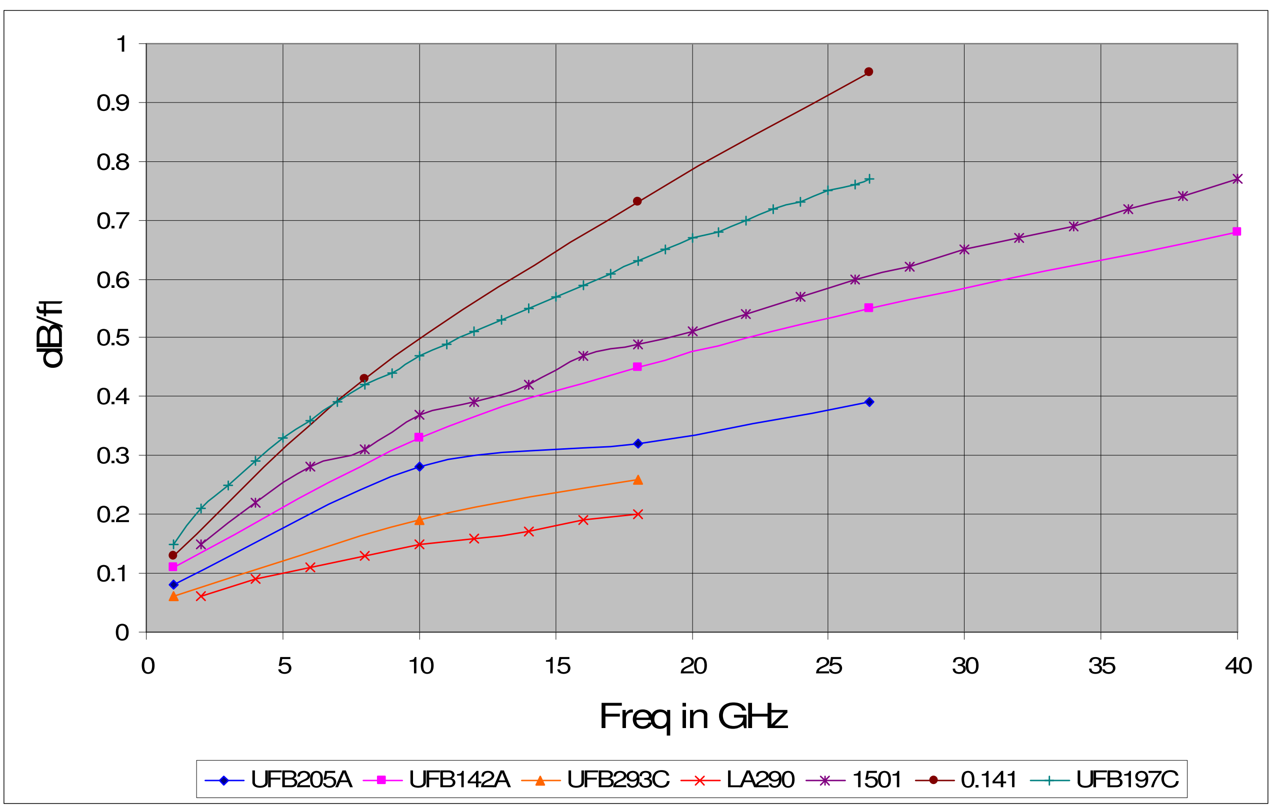

Figure 3 – Insertion loss specifications for typical low loss RF coaxial cables